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On the Flying Squid *Stenotuthis oualaniensis* (Lesson) In Hawaiian Waters*

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Abstract

By the request of Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA), the cooperative research of squid species in Hawaiian waters by Hokusei Maru Training ship of Hokkaido University was began from February, 1981, from two years. Furthermore University of Hawaii hopes for continuation of this research from November in 1983, and planned until 1987.

The present results of this research can be summarized as follows.

1) The predominant species of squid distributed in Hawaiian waters was flying squid *Stenotuthis oualaniensis*.

2) Flying squid was male prior mature and size of male smaller than female. In fully maturity, the mantle length of male was about 145~150 mm and female was about 225~230 mm.

3) Relation between the mantle length (Y) to body weight (X) for female was $Y=0.000018\times^{3.15}$ ($r^2=0.9597$), and for male was $Y=0.000042\times^{2.99}$ ($r^2=0.7006$).

4) In November, immature stage were predominated distribution in Southwest area of Oahu island for both male and female; and three months later in February, in the same area including Southern area of Oahu island was almost unappear.

5) In February, the matured female was concentrated in off Hilo, east coast of Hawaii island. Here was considered as one of the spawning ground of this species, and the spawning season was from February to March.

6) Spawned in off Hilo, during floating period after hatching, they transfered to west-ward by current. The swimming capability increased with growth, they migrate to east-ward reaching again off Hilo spawning ground in February to March. This support our hypothesis.

7) From views of growth and maturity, it is considered that life cycle of *S. oualaniensis* like of other squid of the same family is one year.

8) Flying squid widely distributed in mid-Pacific ocean and Indian ocean. Off Hilo as one of the spawning ground might be indicated that subpopulation of flying squid exist in waters adjacent Hawaiian Islands.

Introduction

To obtain the information of squid species in Hawaiian waters, its ecology and assessment of the resources, Honolulu Laboratory, Southwest Fisheries Center,

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National Marine Fisheries Service, NOAA, requested the cooperative research with Hokkaido University. The agreement of the cooperative research for along three years and was began in February, 1981. Furthermore, University of Hawaii hope for continuation of this research from November, 1983 and planned until 1987. This report describes the present results of this research, particularly distribution,

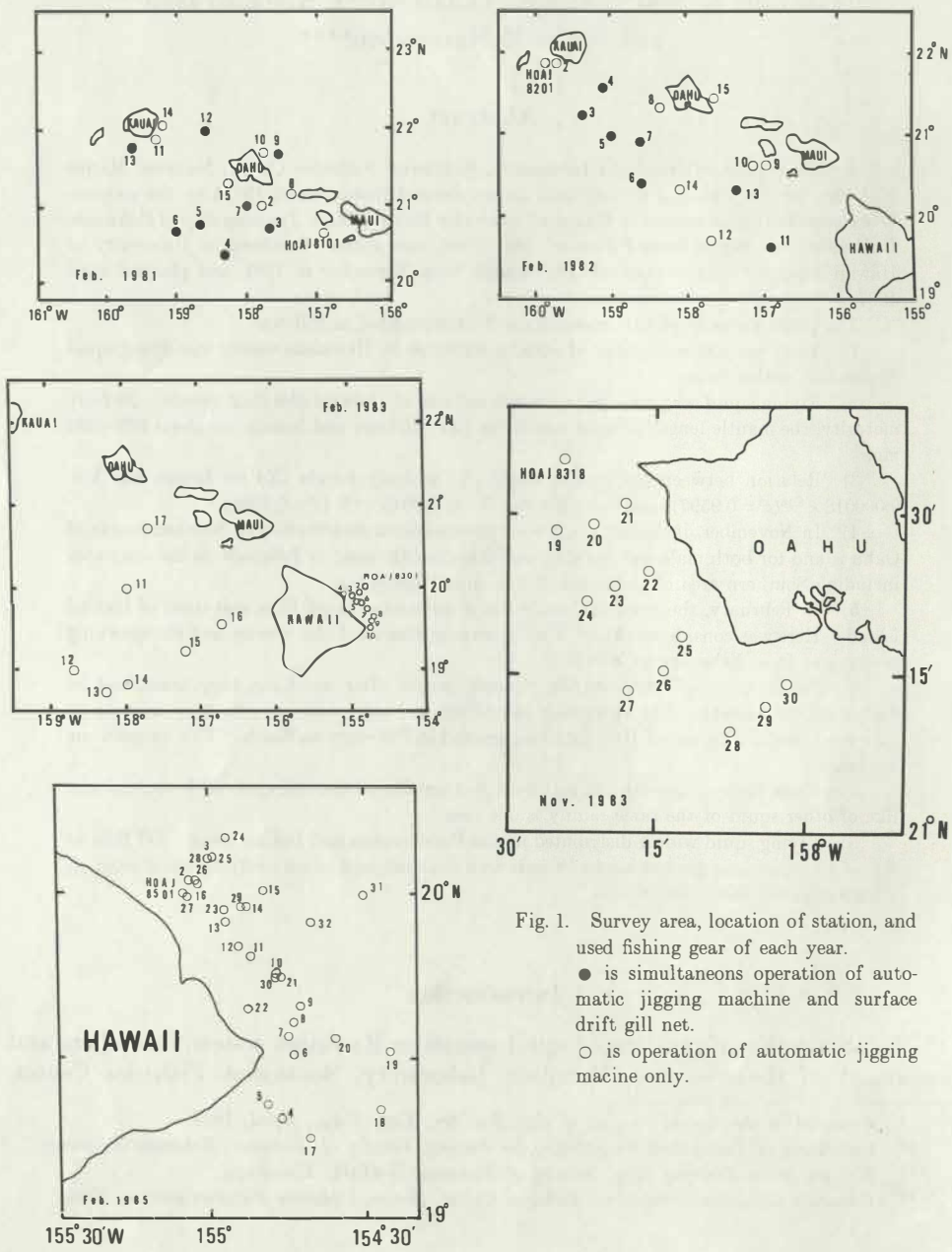

Fig. 1. Survey area, location of station, and used fishing gear of each year.
● is simultaneons operation of automatic jigging machine and surface drift gill net.
○ is operation of automatic jigging macine only.

growth, sex ratio of flying squid *S. oualaniensis* and propose a hypothesis of their life history.

Materials and Methods

The survey was carried out in February for every years with the exception of in 1983 the survey also conducted in November other than in February. The term of survey and used fishing gear are given in Table 1, and survey area and location of stations are shown in Fig. 1.

Fishing gear used in this survey were a double system automatic squid jigging with three machines, one line consisting of 30 squid jigs placed one meter apart and surface drift gill net with 18 kinds of mesh size and total 79 shackles. The mesh size, shackle number of used surface drift gill net and its construction are shown in Table 2.

The survey area was designed to cover of the all waters adjacent to Hawaiian waters except those due to bad weathers.

Table 1 Survey term and fishing gear used for each year

Year	Survey term	Fishing gear
1981	27 Jan. to 12 Feb.	Surface drift gill net and automatic jigging machine
1982	26 Jan. to 12 Feb.	〃
1983	5 Feb. to 21 Feb.	〃
1983	26 Nov. to 3 Dec.	Automatic jigging machine
1985	2 Feb. to 20 Feb.	〃

Fig. 2. Photograph of *S. oualaniensis*

Results

The species of squid captured by surface drift gill net were tobi-ika *Stenotuthis oualaniensis* (Lesson), aka-ika *Ommastrephes bartrami* (Lesueur), tsume-ika *Onychoteuthis banksii* (Leach), Hawaisurume *Nototodares sloani hawaiiensis* (Berry). Because very few number in all catch of surface drift gill net, only data of flying squid *S. oualaniensis* captured by automatic squid jigging machine was investigated[1)2)].

Stenotuthis oualaniensis (Lesson) is species of living in open sea[3)], widely distributed from equatorial waters including Indian Ocean extenting to mid-North and mid-South Pacific Ocean. Morphologically similar to Japanese common squid

Table 2 Mesh size and shackle number of surface drift gill net and its construction

Mesh size	Shackle number	Mesh size	Shackle number
Stray net			
121	5	121	3
48	3	37	6
25	6	72	3
93	3	159	3
55	3	42	6
29	6	82	3
138	3	179	3
106	3	204	3
33	6	233	3
63	3	Stray net	
		121	5
		Total	79

Table 3 Fishing ground, catch of *S. oualaniensis*, ratio of female to

Year	Fishing ground	Catch	Female-male ratio (%)
1981, Feb.	Oahu Is. South	400	75 : 25
1982, Feb.	〃	131	79.4 : 20.6
1983, Feb.	〃	146	72.6 : 27.4
1983, Feb.	Hawaii Is. East	533	81.2 : 18.8
1983, Nov.	Oahu Is. West	760	75.9 : 24.1
1985, Feb.	Hawaii Is. East	369	81.1 : 18.9

‡ Maturity 1 is immature stage, maturity 3 is matured stage

Todarodes pacificus Steenstrup, classifying in family Ommastrephidae and has a special feature that is big photo organ at dorsal as shown in Fig. 2.

Table 3 shows the fishing ground, catch of flying squid *S. oualaniensis*, ratio of female to male, mean mantle length, mean body weight, and maturity of each year. Mean CPUE (catch per unit jigging machine per one hour) and its confidence intervals of each year are given in Table 4.

Figs. 3 (a) and (b) shows histogram of mantle length (a) and body weight (b) of *S. oualaniensis* female in the waters south of Oahu island. The histogram of male are given in Figs. 4 (a) and (b). The composition in south and southwest of Oahu island has approximately same trend in February, 1981, 1982, and 1983, only 1981 was showed as model.

The histogram of mantle length (a) and body weight (b) of *S. oualaniensis* female and male in waters east of Hawaii island in February, 1983 are given in Figs. 5 (a) and (b); and Figs. 6 (a) and (b) respectively. Data obtained from the same waters in February, 1985 also clearly seen approximately same trend.

For the waters southwest of Oahu island, the histogram of mantle length (a) and body weight (b) of female and male in November, 1983 are shown in Figs. 7 (a) and (b), and Figs. 8 (a) and (b), respectively.

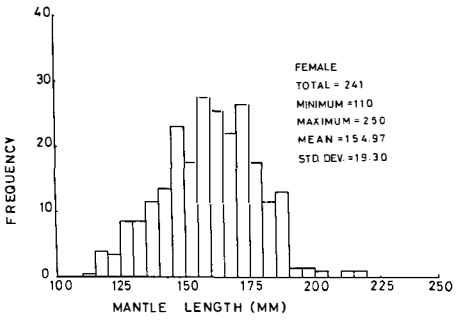

Fig. 3(a). Mantle length composition of *S. oualaniensis* female sampled in waters south of Oahu island in February, 1982.

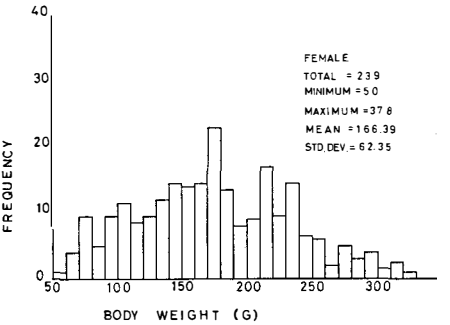

Fig. 3(b). Body Weight composition of *S. oualaniensis* female sampled in waters south of Oahu island in February, 1982.

male, mean mantle length, mean body weigth, and maturity of each year

	Female					Male				
	Mean ML (mm)	Mean BW (g)	Maturity %			Mean ML (mm)	Mean BW (g)	Maturity %		
			1	2	3			1	2	3
0.93	155.0	166.6	96	0	4	139.4	120.4	9	8	82
0.74	164.7	223.6	87.5	0	12.5	147.8	141.5	0	0	100
0.76	164.2	215.1	71.8	14.1	14.1	140.1	123.1	7.5	12.5	67.5
0.49	191.3	390.1	48.7	6.9	44.4	142.6	123.4	27	17	56.0
? 1.17	143.2	122.4 ?	99.9	0	0.03	137.8	105.5	78.6	5.8	15.6
0.49	206.6	419.2	–	–	–	149.4	150.7	–	–	–

0.42 315 743

|ML| < |BW| ?

|ML| > |BW| ...

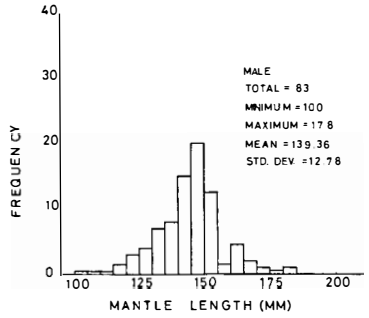

Fig. 4(a). Mantle length composition of *S. oualaniensis* male sampled in waters south of Oahu island in February, 1982.

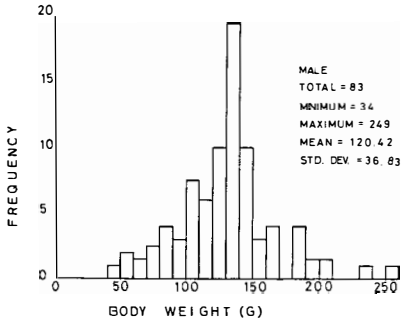

Fig. 4(b). Body weight composition of *S. oualaniensis* male sampled in waters south of Oahu island in February, 1982.

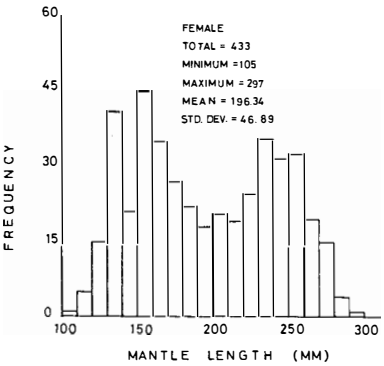

Fig. 5(a). Mantle length composition of *S. oualaniensis* female sampled in waters east of Hawaii island in February, 1983.

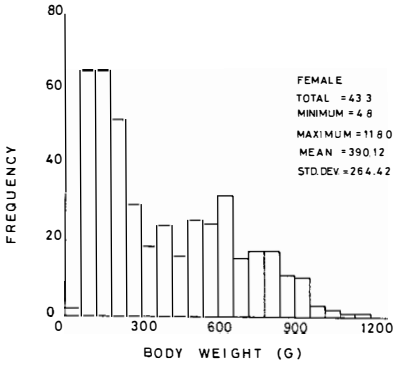

Fig. 5(b). Body weight composition of *S. oualanienis* female sampled in waters east of Hawaii island in February, 1983.

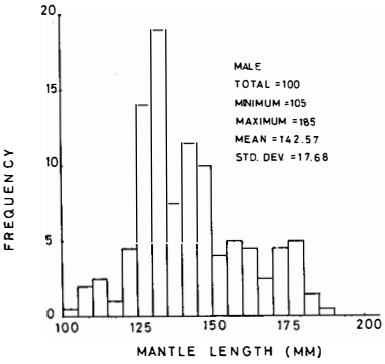

Fig. 6(a). Mantle length composition of *S. oualaniensis* male sampled in waters east of Hawaii island in February, 1983.

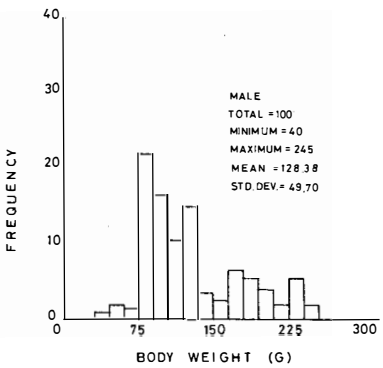

Fig. 6(b). Body weight composition of *S. oualaniensis* male sampled in waters east of Hawaii island in February, 1983.

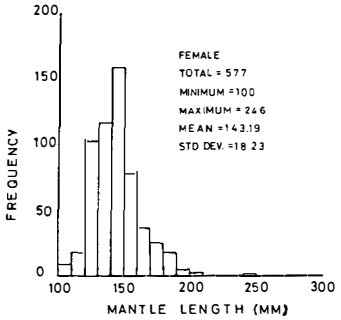

Fig. 7(a). Mantle length composition of *S. oualaniensis* female sampled in waters southwest of Oahu island in November, 1983.

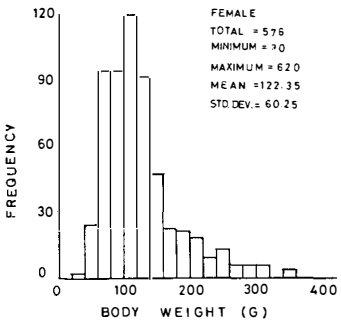

Fig. 7(b). Body weight composition of *S. oualaniensis* female sampled in waters southwest of Oahu island in November, 1983.

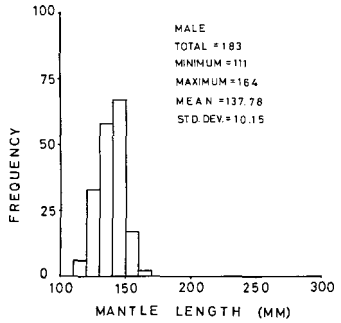

Fig. 8(a). Mantle length composition of *S. oualaniensis* male sampled in waters southwest of Oahu island in November, 1983.

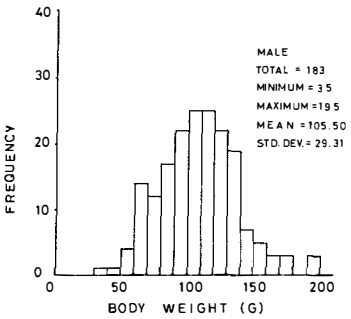

Fig. 8(b). Body weight composotion of *S. oualaniensis* male sampled in waters southwest of Oahu island in November, 1983.

Table 4 Mean CPUE and its confidence intervals of catch year

Year	1981, Feb.	1982, Feb.	1983, Feb.	1983, Feb.	1983, Nov.	1985, Feb.
Fishing Ground	Oahu ls. South	Oahu ls. South SW	Oahu ls. South	Hawaii ls. East	Oahu ls. Southwest	Hawaii ls. East
CPUE	1.43 (0-4.7)	0.5 (0.1-1.2)	0.7 (0.06-1.2)	6.2 (2.9-9.7)	7.6 (3.8-13.3)	2.70 (0.33-6.0)

Results of fitting the mantle length (Y)-body weight (X) relationship of female (1983-1985 years sample) was $Y=0.000018\times^{3.15}$, $r^2=0.9597$ (Fig. 9). Fig. 10 described the mantle length-body weight relationship of male, $Y=0.000042\times^{2.99}$, $r^2=0.7006$.

Further, the water temperature of Hawaiian waters in this season can be

Table 5 Catch of *S. oualaniensis* in off Hilo and southeastern area weight and maturity.

Year	Area	Female-male ratio (%)	Female	
			Mean ML (mm)	Mean BW (g)
1983, Feb	off Hilo	87.5 : 12.2	225.9	548.2
1985, Feb	〃	85.9 : 14.1	228.5	514.74
1983, Feb	Hawaii Is. Southeast	77.4 : 22.6	159.2	190.1
1985, Feb	〃	80.4 : 19.6	136.0	212.4

⁂ Maturity 1 is immature stage, maturity 3 is matured stage.

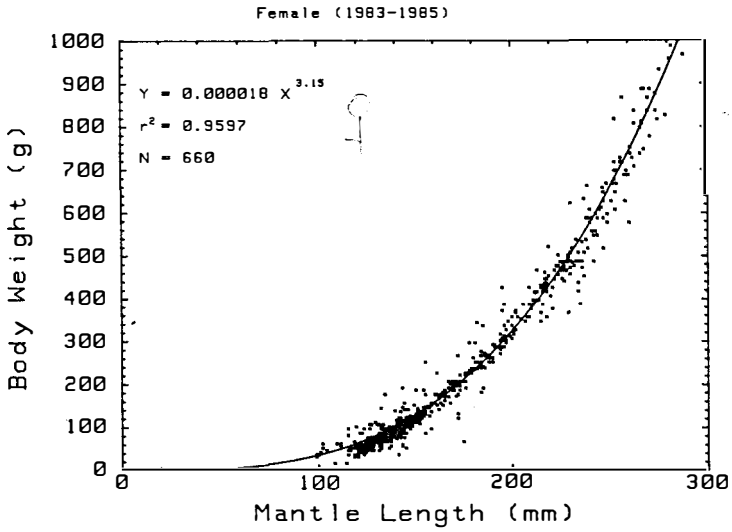

Fig. 9. The relationship between mantle length and body weight of *S. oualaniensis* female.

summarized as follows. The isothermal layer of 24℃～25℃ formed until depth 100 m, deeper than this circumstances, water temperature achieving 5℃ for depth 500-600 m. Other than this depth until adjacent 1000 m formed isothermal layer of about 5℃ again.[1)2)]

Discussion

Very few *S. oualaniensis* were distributed in waters south and southwest of Oahu island in February, 1981, 1982 and 1983, indicated by mean CPUE value of 1.4, 0.5, and 0.7 respectively (Table 4). The mean mantle length 140 mm and body weight 130 g of male illustrated almost matured stage (Table 3). On the other hand, 80-90% of female were immature stage (among these, 80-90% have not mate). Moreover, the mean mantle length 160 mm and body weight 200 g of female indicat-

of Hawaii island and respective mean mantle length, mean hody

			Male					
Maturity %			Mean ML (mm)	Mean BW (g)	Maturity %			CPUE
1	2	3			1	2	3	
16.4	6.5	76.8	147.7	140.6	26.7	13.3	60.0	27.2
—	—	—	156.1	156.1	—	—	—	16.5
90.6	5.2	4.2	141.3	126.2	17.9	14.3	69.7	10.7
—	—	—	138.1	130.2	—	—	—	8.9

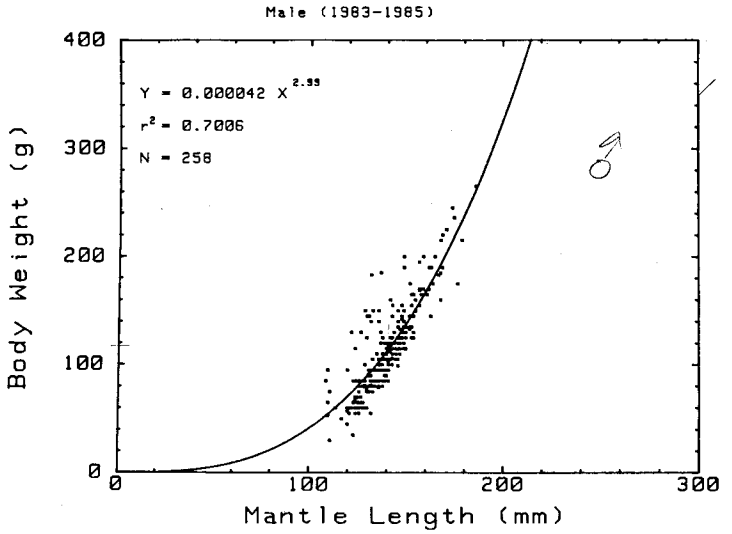

Fig. 10. The relationship between mantle length and body weight of *S. oualaniensis* male.

ed *S. oualaniensis* like other species of squid was male prior maturity and male size smaller than female.

The highest mean CPUE of 7.6 (Table 4) showed high density of *S. oualaniesis* population distributed in southwestern area of Oahu island in November compared to February results. About 80% of male which having mean mantle length of 138 mm and body weight of 105 g was immature stage; and 99.9% of female with 143 mm mean mantle length and 122 g mean body weight was immature. This suggests that the small size of both male and femle may be immature stage.

As shown in Table 4, in February, 1983 and 1985, a very high density (mean CPUE of 6.2 and 2.7 respectively) of *S. oualaniesis* population distributed in waters east of Hawaii island compared to the same season in southern area of Oahu island

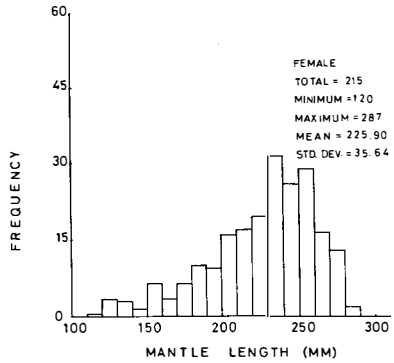

Fig. 11(a). Mantle length composition of *S. oualaniensis* female in waters off Hilo of Hawaii island in February, 1983.

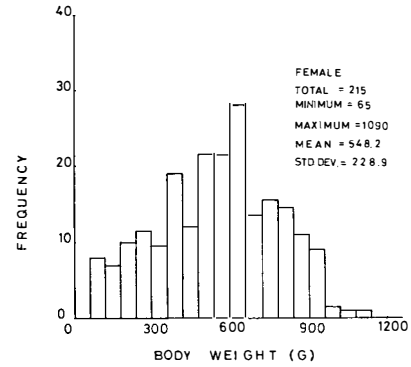

Fig. 11(b). Body weight composition of *S. oualaniensis* female in waters off Hilo of Hawaii island in February, 1983.

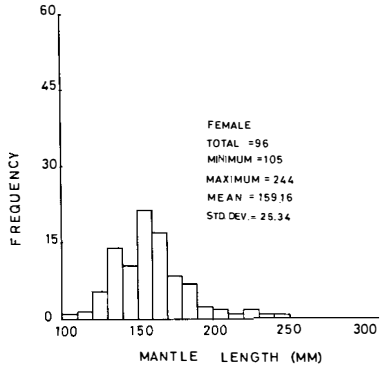

Fig. 12(a). Mantle length composition of *S. oualanienis* female in waters of southeast of Hawaii island in February, 1983.

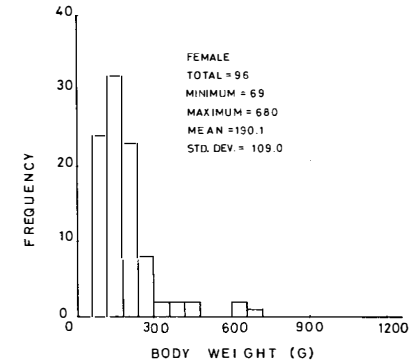

Fig. 12(b). Body weight composition of *S. oualaniensis* female in waters of southeast of Hawaii island in February, 1983.

as described above. The mantle length and body weight of male has almost same as another area. But the female has mean mantle length of about 200 mm and mean body weight of about 450 g, which is a very large size. The degree of maturity also high, about 50% was fully in matured condition (in 1985 season only mantle length and body weight were measured).

Because of clearly seen the different size of female body, in the east of Hawaii island, the central off Hilo of Hwaii island (St. HOAJ 8301-8303, St. HOAJ 8526, 28, 29, 30, 32 in Fig. 1) and waters southeast of Hawaii island (St. HOAJ 8308-8310, St. HOAJ 8505, 17-20 in Fig. 1), these data was rearranged.

The mantle length and body weight of off Hilo and southeast off of Hawaii island given in Fig. 11 and Fig. 12, respectively. Table 5 shows the respective mean mantle length, mean body weight and maturity obtained off Hilo and waters southeast of Hawaii island. Based on these data, the population of off Hilo was

large size matured, and immature for waters southeast of Hawaii island. The CFUE of off Hilo also indicated by large size matured female stage was concentrated in this area.

Figs. 9 and 10 show the mantle length-body weight relationship of female and male, respcctively. The mean mantle length of female of off Hilo in November achieving 143 mm, three months later in February this mantle length was 225 mm. It is considered that this mean mantle length composition suggests the mean growth rate. Besides, based on the results as shown in Figs. 9 and 10, and maturity stage in Table 3 and 5, it is conjectured that flying squid has same life cycle with other squid species of family Ommastrephidae.

From the results that matured stage was concentrated in off Hilo, this area was considered as one of the spawning ground. Spawned in off Hilo, during floating period after hatching, they transfered to westward by northern equatorial current from Oahu island to surrounding Hawaii islland. The swimming capability increased with growth and then they migrate to east ward reaching surrounding Oahu island again, from October to December become distributed as immature stage. Eventually they reach to spawning grounnd of off Hilo of Hawaii island, during a period from January to March. This pattern was considered as the life cycle of *S. oualaniensis* in Hawaiian waters (Fig 13). In November the high abundant immature stage was distributed in waters southwest of Oahu island, and low abundant distributed three months later (in February). This supports our hypothesis.

Also from the previous report[3], it was described that flying squid *S. oualaniensis* distributed in illimitable areas, from Indian ocean to the center part of Pacific ocean and exist subpopulations. So it is considered that the subpopulation of *S. oualaniensis* which can distributed in waters adjacent Hawaii islands. The spawn-

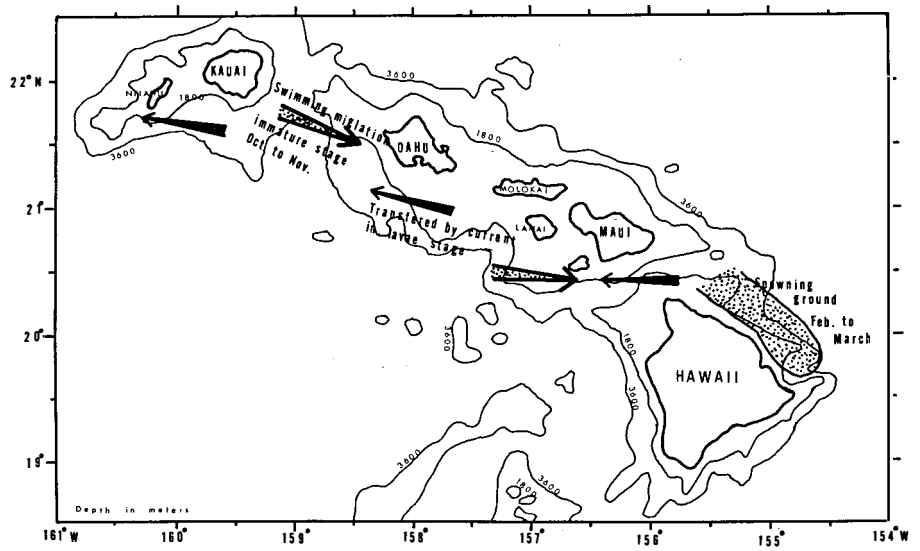

Fig. 13. Schematic representation of the life cycle period of *S. oualaniensis* in Hawaiian waters in February to March spawning population (Hypothesis).

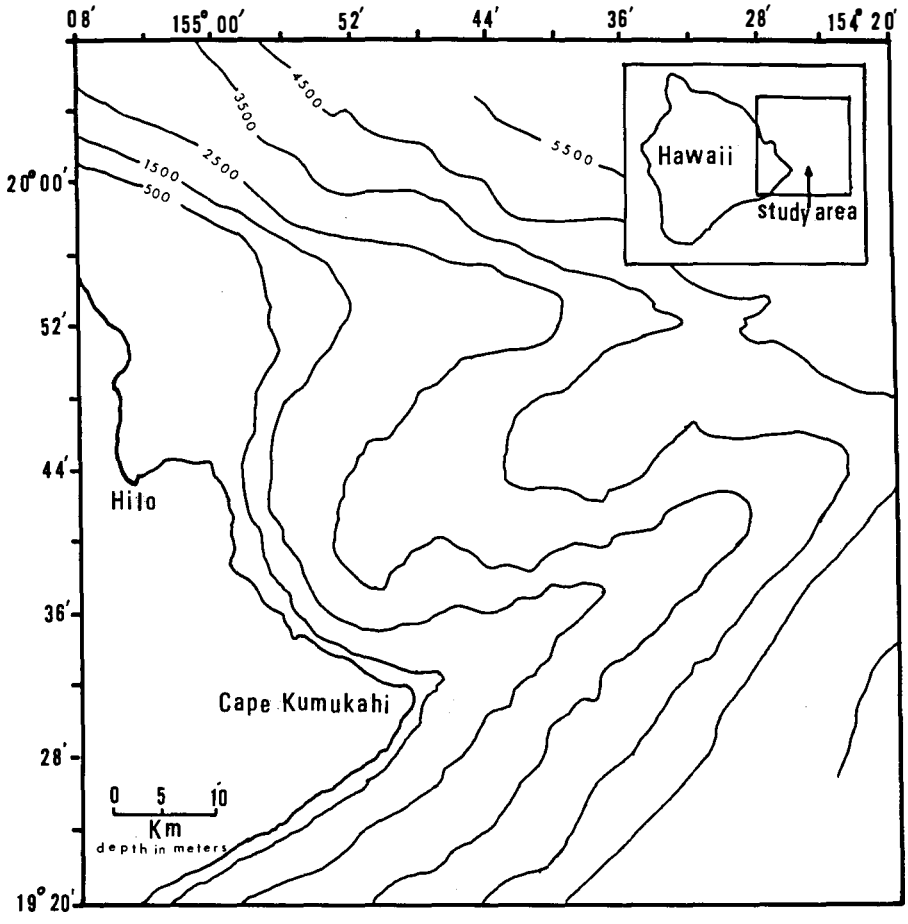

Fig. 14. Depth contours off Hilo of Hawaii island.

ing ground of this subpopulation was considerd in off Hilo. Hereafter, to gather more detail information, continued research is very important.

Why off Hilo was considerd as one spawning ground, the reasons investigated[4] consist of nutrient salts, plankton distribution, water temperature, and salinisy. At present time, the particular cause could not be founded. Fig. 14 shows the depth contours of off Hilo, Hawaii island. At the southern Hilo, it has outlet of sea trench, depth of this part of ridge shallower than surrounding parts. The topography of this ara could be significant to understand why this area could be a spawning ground by *S. oualaniensis* and must be studied carefully in future.

Other hand Hilo fisherman[5] reports that many matured stage *S. oualaniensis* gathered at off Hilo same area in August. This fact is suggested to exist another subpopulation of *S. oualaniensis* in Hawaiian waters, but we have not any informations in this matter. So necessary to research other seasons in future.

Acknowledgements

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